Aerospace Structures Information and Analysis Center

Flight Dynamics Directorate (FDD) Research and Development for Aging Aircraft

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The current trend is for military and commercial aircraft to be used beyond their original design life as well as for a longer calendar time. To support this trend structures research and development must include a focus on topics that will support aging aircraft. The identification of these R&D topics included a review of the technical papers that were presented at the June 1993 Conferences of the International Conference on Aeronautical Fatigue (ICAF) and the 5th International Conference on Structural Airworthiness of New and Aging Aircraft; ideas were also obtained from the USAF sponsored Aircraft Structural Integrity Program (ASIP) Conference held in November 1993. These R&D topics have been grouped into six technical areas.

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FOREWORD

This report was prepared by the Aerospace Structures Information and Analysis Center (ASIAC), which is operated by CSA Engineering, Inc. under contract number F33615-90-C-3211 for the Flight Dynamics Directorate, Wright-Patterson Air Force Base, Ohio. The report presents the work performed under ASIAC Task No. 42. This effort was sponsored by the Structural Integrity Branch, Structures Division, Flight Dynamics Directorate, WPAFB, Ohio, with Mr. Christopher Clay as the technical monitor. The analysis was performed by Mr. James R. Johnson.

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I. Introduction

The current trend is for military and commercial aircraft to be used beyond their original design life as well as for a longer calendar time. To support this trend, structures research and development must include a focus on topics that will support aging aircraft. The identification of these R&D topics included a review of the technical papers that were presented at the June 1993 Conferences of the International Committee on Aeronautical Fatigue (ICAF) and the 5th International Conference on Structural Airworthiness of New and Aging Aircraft; ideas were also obtained from the USAF sponsored Aircraft Structural Integrity Program (ASIP) Conference held in December 1993. These R&D topics have been grouped into six technical areas:

1. Flight Loads Prediction, Measurement and Analysis,
2. Structural Fatigue and Fracture Life Prediction Techniques,
3. Corrosion Control, Prevention and Life Prediction Models Incorporating Corrosion Effects,
4. Non-Destructive Inspection and Evaluation Techniques,
5. Fatigue Life Enhancement Schemes, and
6. Design, Structural Concepts and Test Techniques.

For each topic, a short paragraph summarizing the need is presented. For each of the six areas, references are provided for the technical papers that were presented at the ICAF and Airworthiness Conferences where more detailed information that relate to the needs may be obtained. The references cited are the most recent available but in no way are they a complete tabulation of those available.

II. Flight Loads Prediction, Measurement and Analysis

[Ref: 2, 3, 19, 22, 23, 25, 28, 29, 30, 31, 35, 40, 41, 45, 47]

a. On-board processing ...criteria for future designs
...departures from design missions
...individual aircraft tracking (IAT)

The technology is in place to perform on-board processing for individual airplane tracking and design criteria purposes. The need that exists is to estimate the long term benefits and costs associated with such a move. Major impacts expected would be in the reduction of data processing required at Aircraft Structural Integrity Management Information System (ASIMIS) facilities and reduction of flight line maintenance personnel time. An increase in the quality of data could be expected as well as an increase in the quantity of data collected.

b. Simplified IAT with fewer parameters. As individual aircraft tracking techniques have developed over the past three decades their complexity has increased. This is understandable since the aircraft and their operations have increased in complexity also. However it is timely to examine the utility of the various techniques that are in use today. Of particular interest would be the parameters being recorded and the extent that they are being analyzed and used. This study could lead to decisions that might simplify the IAT procedures for new aircraft and reduce data reduction needs of data being recorded on existing aircraft.

c. Establish and track design spectra/usage spectra for USAF commuter type aircraft. As off-the-shelf aircraft are purchased for USAF use the usage needs to be tracked for the purpose of comparing the design spectra with the actual usage spectra. The impact of this comparison on the structural life can then be determined.

d. Verify atmospheric turbulence models. Atmospheric turbulence models currently in use were developed many years ago. There is some current work underway in the Netherlands that is sponsored by the Federal Aviation Administration (FAA) as part of their aging aircraft program but this is specifically directed toward commercial aircraft. These turbulence models

need to be reviewed and any recent data incorporated so that they may be as current as possible for application to military aircraft.

e. Transfer/use USAF load monitoring techniques for commercial aircraft. The experience level in the USAF on load monitoring techniques is high. While the commercial airlines are reluctant to incorporate load monitoring techniques, it is sure to come. The USAF could enter partnerships and transfer this technology to commercial industry and the airline operators.

f. Empennage loads. Understanding of tail loads continues to be illusive, particularly buffet. While causes and effects are generally understood or explained after the fact, more emphasis needs to be placed on a basic understanding of tail loads and their prediction. While emphasis should be placed on twin vertical tail aircraft, all configurations should be studied.

III. Structural Fatigue and Fracture Life Prediction Techniques

[Ref: 1, 2, 3, 4, 5, 9, 10, 11, 13, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 29, 30, 33, 34, 35, 37, 38, 39, 40, 43, 44, 45, 46, 47, 48, 49]

a. Crack initiation/crack propagation models. Historically, the USAF based life prediction techniques solely on a fatigue approach. In the early 1970's a change was made with the abandonment of the safe-life approach based on fatigue to a damage tolerance approach based on crack propagation techniques for safety and choice of the classic fatigue approach or a crack propagation approach for durability. There is still the possibility that a combined fatigue/crack propagation approach that will represent the total life of the structure can be developed. Fundamental research needs to continue to explore this approach.

b. Probabilistic techniques. Most current damage tolerance and durability approaches to life prediction are based upon deterministic methods. Probabilistic techniques permit the establishment of risk that will aid the operational commander in his decision making process. A necessary ingredient of the probabilistic approaches are the experimental data required that are often not available in sufficient quantity for a rigorous analysis. Continued emphasis needs to continue in probabilistic analytical techniques as well as generating or collecting experimental data to support the approach.

c. Widespread fatigue damage/multiple site damage including secondary bending. Investigations of WSD/MSD should include the effects ofload transfer or load redistribution and secondary bending on structural integrity. An analytical investigation supported by experiments should incorporate open hole specimens, fastened joints including stiffened panels and multi-axially loaded panels. The phenomena investigated should include crack initiation, crack propagation and residual strength.

d. Techniques including temperature - exhaust impinged areas. Temperature adds another complication in the life prediction process. With funding by the National Aerospace Plane Program and previously funded efforts supported by Wright Laboratory (WL), basic

approaches have been formulated. While the target of opportunity may have diminished, a long term effort should be conducted to develop life prediction techniques for thermal structures, i.e. thermal fatigue problems exist in subsonic aircraft.

e. Buffet including ripple loads on a high mean load. Buffet loading conditions - wings or tails - are difficult to predict and the resulting structural life prediction techniques are marginal. When the buffeting is superimposed upon a maneuver load the life degradation can be significant. Analysis techniques and experimental tests to confirm the results should be accomplished.

f. Identification and documentation of WFD/MSD in service aircraft. Case histories should be documented, both commercial and military. The geometry, loadings, materials and environments need to identified as accurately as possible. These type of data would provide insight to other identified tasks.

g. Evaluate WFD/MSD thresholds, initial crack distributions and equivalents and interactions. Through teardowns and inspections of structures that have experienced multi-site damage or wide spread fatigue damage, the geometry, loading and the environment that lead to the cracking should be established and documented. Upon examination of many situations thresholds should be able to be established as guidelines for designers. These investigations should also establish the type and distribution of initial crack distributions once the conditions are present for initiation. For laboratory element or component tests actual distributions or their thought-to-be equivalents can be determined for comparative purposes.

h. Life of compression dominated structure. While fatigue is usually considered as a tension dominated phenomena, it frequently can occur in structure where the principle loading is compressive. Ground-air-ground cycles have a major influence on life. Also, local bending or rotation of structural elements can introduce tensile forces that can lead to earlier than expected failures.

IV. Corrosion Control, Prevention and Life Prediction Models Incorporating Corrosion Effects

[Ref: 1, 12, 18, 29, 30, 31, 32, 36, 37, 38, 45, 47, 50]

a. Corrosion prevention techniques. The fundamental techniques to prevent corrosion in structures are known. Often, however, these fundamentals are ignored or overlooked in the design cycle or by the operational unit. While not necessarily the purview of the Structures Division, emphasis needs to be placed on the preventive measures in order to minimize the loss of operational readiness and to help reduce maintenance costs.

b. Stress intensity factor(s) for corroded geometry. Examine corroded structure to determine its geometry; approximate the corroded structure with a geometric equivalent; conduct analyses; obtain experimental correlation.

c. Da/dn data generation for corrosive environments and insertion into models. A typical approach is to account for a corrosive environment in the crack propagation approach by developing the appropriate da/dn data. Corrosive environments need to be identified and those that do or could have a significant effect on the life or corrosion behavior of a structure need to have the data generated for use in a life prediction model.

d. Determine effectiveness of previous corrosion treatments and prevention measures. There is probably not an airplane that does not have corrosion treatment or repair at some point in its lifetime. A review of these records might provide insight to specific elements that are causing corrosion, and the behavior and effectiveness of corrosion treatments. These data could provide insight for R&D activities.

e. Develop laboratory test simulation techniques. Corrosion tests usually consist of immersion of an element or coupon into a bath of a corrosive environment. Some tests have been conducted with a cyclic bath and alternate periods of drying. Test techniques with the application of load and any other significant environments should be examined. The objective

would be to seek a more realistic simulation in the laboratory and the risk of a more complex test set up. If feasible, an evaluation of new/revised design concepts could be verified prior to incorporation into full-scale development. If successful the cost savings to the USAF would be immense.

V. Non-Destructive Inspection and Evaluation Techniques

[Ref: 1, 8, 9, 21, 29, 30, 32, 33, 34, 35, 37, 38, 40, 41, 45, 46, 47, 48, 49, 50, 51]

a. Periodic proof/overload pressure tests of fuselages. One means of inspecting a fuselage for cracks would be a pressure test. By selecting a pressure greater than flight pressure then there would be a certain number of pressure cycles that the fuselage could withstand. Then the pressure test must be performed again. Controversially, the use of pressure tests could cause damage that is not understood. A white paper should be written to summarize the pros and cons of each side of the issue.

b. Teardown of high damage and/or long-term aircraft. While expensive, the teardown of an aircraft with significant corrosion/corrosion fatigue areas would provide insight on the behavior of corrosion prevention techniques, the ability of non-destructive inspection techniques to identify hidden corrosion areas and the behavior of various design concepts in corrosive situations. An alternate approach would be the teardown of selected components; this would provide the opportunity of multiple specimens of the same structural configuration or many different configurations.

c. Upgrade reliability curves for inspection techniques. It has been several years since the reliability curves have been established. Update data for existing inspection techniques and develop similar data for any new techniques.

d. Multilayer inspection technique w/o fastener removal. Since it is costly and conceivably damage could be caused with fastener removal, research should be continued on techniques that can determine cracking in sub layers of a structure.

e. Surface inspection techniques. The Diffracto-Sight (D-sight) technique shows much promise as an inexpensive inspection technique. The technique, has proven to be effective in verifying fastener hole cold working, in identifying surface and sub-surface corrosion and in sensing impact damage on composites. A contract is currently funded by the FAA to further

develop this technique. The technique should be reviewed for USAF applications.

f. Defect reporting methods. Current documentation requirements are not conducive for encouraging the accurate reporting of damage in fleet aircraft. It might prove beneficial to have some human factors people along with engineering personnel examine current forms and try to come up with a better scheme. A paperless approach shouldn't be discarded and in fact ought to be encouraged.

g. Poor/weak bond inspection techniques. Effort needs to be continued on inspection techniques to detect poor or weak bonds. In addition to single layer inspection a technique needs to be developed for double or multiple layers consisting of metals or composites in any combination.

h. Improve reliability and reduce cost of inspections. For existing inspection techniques ways need to continue to be developed to remove the drudgery from the process and to enhance data recording and analysis.

i. Exploit acoustic sensing of defects/damage. Some organizations report success with acoustic sensing of structural damage while it is happening. The technique, if and when it is economically viable, could have application in the structures test lab and flight vehicles. There is much skepticism in the results although recent advances in detection and data analysis techniques have provided hope for more practical and reliable applications.

j. Corrosion detection between layers and beneath fastener heads. This activity is similar to the requirement for inspection for cracking beneath fastener heads and between layers. This is a much more difficult task since there is unlikely to be any surface effect that could be detected by an optical light technique such as D-sight. Therefore, electrical techniques are the most promising to pursue.

VI. Fatigue Life Enhancement Schemes

[Ref: 4, 6, 24, 26]

a. Review cold-working situations/geometries and enhancement schemes. There is wide spread use of cold-working of fastener holes, primarily in rework situations but there is some application to new construction also. A primer should be developed that would provide guidelines for the application of cold-working techniques.

b. Laser shock processing. Laser shock processing was investigated as a fatigue life enhancement method in the early 70's. The approach was investigated principally for application around the surface of fastener holes. There is renewed interest in this approach for application to propulsion components. At the same time, further development could be studied for application to airframe components.

c. Shot peening. Shot peening, when compared to cold-working for fatigue life enhancement, is considered as a "shallow" treatment. The benefits include the ability to treat large surface areas economically. Recent techniques permit the shot peening of fastener holes. A test program to evaluate the effectiveness of this technique should be conducted. A partnership could probably be developed with a supplier to shot peen specimens furnished by WL and cyclic tests performed by WL.

d. Comparison of split mandrel and split sleeve processes. Presently the vast majority of cold-working is accomplished by the split sleeve process although there is a similar approach called the solid sleeve process. A new technique called the split mandrel process has recently been developed. The claim is made for more economical cold working than the split sleeve process. The structural fatigue performance of this technique needs verification. This could be accomplished by WL conducting element or coupon tests with the cold-working treatment supplied by the competitors on specimens furnished by WL.

VII. Design, Structural Concepts and Test Techniques

[Ref: 1, 18, 19, 20, 22, 23, 24, 25, 26, 28, 29, 30, 31, 32, 34, 37, 38, 39, 41, 43, 45, 46, 47, 49, 53]

a. Criteria for repair. Guidelines for the permanent repair of structure exist in the form of the Mil Std for durability, damage tolerance and static strength. For situations such as battle damage repair or for a one time ferry flight, for example, repair techniques exist. While the on-site unit commander can make judgements about the conditions of the aircraft that can be considered as operationally ready, it would be helpful to have some established guidelines documented for reference for these situations where it may be prudent not to return the aircraft to its full structural specification requirements.

b. Techniques and criteria for multiple, adjacent and repair on repair. Structural failures can arise in service that are not covered by existing repair techniques and criteria. Situations where the failures or repairs of failures are in proximity to one another need to be studied. Guidelines can then be established to insure that successive repairs do not aggravate the structure.

c. Tolerant adhesives. As more and more adhesively bonded advanced composite repairs are used there continues to be a need for adhesives that have a longer shelf life and are less sensitive to storage temperature. These attributes would permit less demanding storage conditions and reduce the cost of these types of repair.

d. Self healing structures. Under the right environmental and loading conditions damage in composites and cracks in metals will increase in severity. A long term project should be initiated to investigate whether there are substances that could be introduced into the material or the structure that would slow, retard or heal the growth of damage. The substance would be dormant but upon cracking of the structure the substance would react with external conditions to produce the desired effect.

e. Rivetless nut plate behavior. A concept has been developed that attaches a nut plate to the structure without rivets. This concept eliminates possible locations for the initiation of damage (rivets) but it introduces other questions mostly in the environmental and strength areas. This topic would be a possible cooperative program with the company that has developed the concept. The company would supply the specimens and WL could perform the testing required on elements.

f. Develop test methods (element and component) to include corrosive environments. Full-scale and component structural testing becomes expensive as environments are introduced into the test setup; experience with heat, fuel, cryogenics are self evident. However, introducing the corrosive environment into structural testing of components and possibly full scale components should be investigated. As aircraft are used for a much longer calendar time, the corrosive environment will play a more dominate role in the life and maintenance cost. A procedure to investigate the corrosive behavior in the laboratory could offer large savings in airplane structure life cycle cost.

g. Develop accelerated corrosion fatigue test techniques. In conjunction with the development of test techniques for corrosive environments, ways should be sought that accelerate the process to shorten test time and thus reduce costs and provide the results earlier. Considerations should include the thermal effect on the corrosive substance, time of application and a cyclic application and increased concentration.

h. Integrated design methods. Structural optimization procedures are receiving much interest and application in structural development but the application to an aircraft in production has yet to happen. As confidence builds toward that application, the optimization technique needs to be expanded to include lifing effects. The lifting should be elaborate enough to satisfy the durability and damage tolerance requirements as opposed to merely a cap on the stress level to provide a fatigue life estimate.

i. Integrated Product Development(IPD). The inspectability of the structure should be a factor included in the IPD process. This will influence the design concept chosen and

insure that problems as they arise will be in a more favorable light if found and more easily corrected.

j. Re-evaluate fretting, wear on structural life. As aircraft are used much longer than their original design life the phenomena of fretting and wear could assume a more dominate role in structural life. Little attention is paid to these conditions today; A summary or guidelines for designers should be developed.

k. Design concepts to minimize MSD. MSD cases should be examined to determine the geometric characteristics, how MSD develops and the conditions that lead to it. By documenting these events, insight might be obtained that could lead to better design concepts for structures to resist MSD. These concepts would be applicable to new designs as well as repairs or modifications to existing structures.

l. Evaluate existing design concepts for time for MSD to appear. MSD case histories should be examined to identify the onset of MSD, the initial conditions or "quality" of the construction and the loading and environmental conditions that lead to the formation of the MSD.

m. Update design and repair handbooks. Several "handbooks" have been published in the form of technical reports on topics such as damage tolerance, durability, repair, force management, stress analysis and advanced composites. These handbooks have proven to be of value to the analyst and the designer but they are in need of updating. The possibility exists of entering into an agreement with an organization to update the handbooks, market the handbooks and share in the profits. This sharing could take the form of reduced contractual payments to the contractor.

n. Qualification of repair/modification centers ...third world countries.
Repairs/modifications to USAF aircraft have been and will no doubt continue to be made by foreign firms as well as US firms. As technology expands into less developed countries, it seems plausible that favorable economic conditions could evolve where it would be

economically attractive for USAF operators to have repair/modification work accomplished by third world countries. A study should be accomplished to identify problems that have occurred in similar facilities, postulate potential problems and develop training and qualification procedures as requirements for new businesses entering into the market.

o. GLARE and ARALL for repair. These glass and arimid fiber composite concepts offer additional alternatives to carbon fiber composite and metallic concepts for the repair of structures. The potential applications, strength, durability, damage tolerance, storage limits and repair concepts need to be identified; research gaps need to be addressed.

p. Accuracy of analysis methods, flight measurements and test techniques. The life of a structure is very dependent upon the local stress level. A change of 10% can half or double the life. A systematic evaluation of the accuracies and the errors to be expected in all phases of the design, analysis, test and tracking phases of an aircraft needs to be accomplished. This would provide a focus on where and how research funds might be best spent to improve the knowledge and understanding of structural behavior.

q. Increasing use of composites ...effect on criteria. Design criteria are often overlooked as new procedures are introduced into aircraft construction. As advanced composites continued to incorporated into aircraft with increasing frequency, the guidelines for their use need to be examined and documented. The The F-22, B-2 and the C-17 offer starting points for an activity such as this.

r. Document lessons learned. One of the most expensive mistakes is a mistake that is repeated. Place more emphasis on the documentation of problems in structural development or operational experience. These need not always be detailed accounts but of sufficient documentation, including personnel references, so that an interested individual could dig deeper if desired. The Aerospace Structures Information and Analysis Center (ASIAC) would be a natural repository for this information as well as any structures experience data.

s. Composite patch behavior in service aircraft. The use of advanced composites for

structural repair is increasing in the US as well as foreign countries. It is an opportune time to survey the applications to date, identify the successes and failures, determine why and then address the identified problems with research.

t. Strain gage reliability in flight test programs and in service aircraft. Strain gages are used in some tracking programs and in all flight loads measurement programs. Short-term behavior does not seem to be a problem but long-term behavior (years) seems to be questionable. There is sufficient use in domestic and foreign aircraft to put together a story on strain gage behavior in long-term applications. These would provide a basis for research by identifying problems and would establish a creditable baseline for usage of existing strain gages. Potential research topics would also be identified.

u. Effectiveness of current ASIP programs. A survey of the ASIP managers at the Air Logistic Centers (ALCs) should be made to identify the strengths and weaknesses of the current approach to ASIP. The outcome of this survey would be to identify areas where the WL personnel might offer short-term help - analysis or testing, for example - or longer term needs that could be addressed with research.

v. Smart structures: costs and benefits. One of the biggest concerns of introducing new technology into aircraft is the cost. Smart structures, or the elements thereof, are no exception. There needs to be a continuing effort to identify the benefits of smart structures technologies and the costs of developing and implementing these technologies. These technologies can be programmed for introduction into new or existing systems in a building block approach so as not to present a major financial burden at any given time.

w. Costs of implementing ASIP programs. Very little data exist on the cost of implementing ASIP programs and the presumed savings. This should be accomplished in major blocks of efforts/funds and be played against factors such as operational readiness, replacement cost and possibly repair-as-necessary criteria. An integral part of this effort would be the tracing of operational problems back to the performance or lack of R&D in the development phase of the system to determine the impact.

x. Structural damping. Structural damping techniques incorporating viscoelastic materials appear to offer a cost effective way of reducing the magnitude of the vibratory stresses in structures and thus increasing their life. The technique is most effectively applied during initial design but the applications to date have been primarily as a modification to existing aircraft to solve a maintenance problem. In addition to continuing to develop the technique and to search for applications, the applications to date need to be monitored for cost and structural effectiveness.

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3. M. Chaudonneret, "Fatigue Loads of Aeronautical Components: Validation of Life Prediction Models From Representative Testings on Aluminum Alloy Specimens"

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6. T. Ozdemir, et al, "Residual Stress Distribution Around Cold Expanded Holes"

7. A. Shimamoto, et al, "Dynamic Crack Curving at Tear Strap with Simulated MSD"

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14. J. H. Park, et al, "Fatigue Growth of Multiple Cracks Emanating from a Row of Fastener Holes and its Effect on Residual Strength of Stiffened Fuselage Panels"

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18. S. Kobayashi, "Optimum Aircraft Structural Design and Verification for Users"

19. J. O'Hara, "The Evolution of the BAe Hawk Design and Structural Clearance"

20. K. E. Brown, "Full Scale Structural Testing as a Tool in Managing Aging Aircraft"

21. R. Boetsch, et al, "Aerospatiale Probabilistic Method Applied to Aircraft Maintenance"

22. H. Ansell, et al, "Design Parameters and Scatter in the Aircraft Sizing Process - Aspects of Durability and Damage Tolerance"

23. J. W. Lincoln, "Assessment of Structural Reliability Derived From Durability Testing"

24. M. Gottier, et al, "Application of Full Scale Test Results to Structural Modification"

25. N. J. Fraterman, et al, "Results of Fatigue and Damage Tolerance Test on Fokker 50

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28. J. Takagi, "Fatigue Test for CRFP Horizontal Stabilizer"

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29. J. W. Bristow, "An Overview of the Regulation Issues"

30. W. J. Sullivan, "Status of the FAA Aircraft Certification Service Aging Airplane Activities"

31. F. J. Leonelli, "Structural Airworthiness of New and Aging Aircraft"

32. H. Claasen, "Developement of Maintenance Programs for Airplane Structures From the Initial Phase to the Present Time Considering Aging Aircraft Problems"

33. K. H. Galda, "Large Scale Aircraft Maintenance Third Party Work"

34. S. R. Erickson, "Maintenance Programs for Aging Aircraft - A View from an Industry Association"

35. A. J. Emmerson, "Some Observations on Fatigue Life Management"

36. F. Workley, "Environmental Concerns of Maintaining Aging Aircraft"

37. P. J. Bashford, "Manufacturers Aspects - Large Airplanes"

38. J. F. McGuire, "Structural Airworthiness of New and Aging Airplanes"

39. E. L. Ralston, "Industry-Agency Safety Development Integration - An Aircraft Manufacturer's Point of View"

40. R. Abbott, "Service Life Evaluation for Small Airplanes"

41. J. C. C. Fiedeldeij, "Fokker F28 Life Extension"

42. S. Kamil, et al, "Industri Pesawat Terbang Nusantara"

43. T. Swift, "Widespread Fatigue Damage Monitoring - Issues and Concerns"

44. C. E. Harris, et al, "Advanced Structural Integrity Analysis Methodology for Airframe Structures"

45. H. Ansell, "Current Aging Aircraft Research Activities in Europe - An Overview of Related Programmes and Projects"

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47. J. W. Lincoln, "USAF Research and Development Programs for Aging Aircraft"

48. H. J. Schmidt, "Industry Research and Development Needs - Regarding Inspection and Maintenance Technologies for Aging Aircraft"

49. J. Lewis, "Technical Issues in Aging Airplane Research and Development"

50. J. S. Heymann, et al, "New Capabilities for Airframe NDE"

51. W. T. Shepherd, "Human Factors Issues in Commercial Aircraft Maintenance and Inspection - Applications of Advanced Technologies"

52. F. J. Leonelli, "Safety Performance Analysis System(SPAS)"

53. M. M. Ratwani, "Repair of Composite and Metallic Aircraft Structures"